Hauser Feshbach Calculations in Deformed Nuclei

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Hauser Feshbach Calculations in Deformed Nuclei

- Bohr Hypothesis:

  Compound reaction has relative decay probabilities independent of entrance channel.

- Weisskopf Ewing (1940):

  $\sigma(E) \propto \sigma_{inv}(E)\ E\ \rho(E^{*}\text{-}B\text{-}E)$

  No J or π dependence

  Often unreliable for smaller decay channels

- Hauser Feshbach (1952)

- Wolfenstein (1952):

$$\frac{\pi \ x^2}{(2I_1+1)(2I_2+1)}\left(\sum \frac{(2J+1)T_{in}T_{out}}{\sum T_{out}}\right)$$

Sum is over compound nuclear *J* and parity π

No specifications of *K* (spin projection on symmetry axis)

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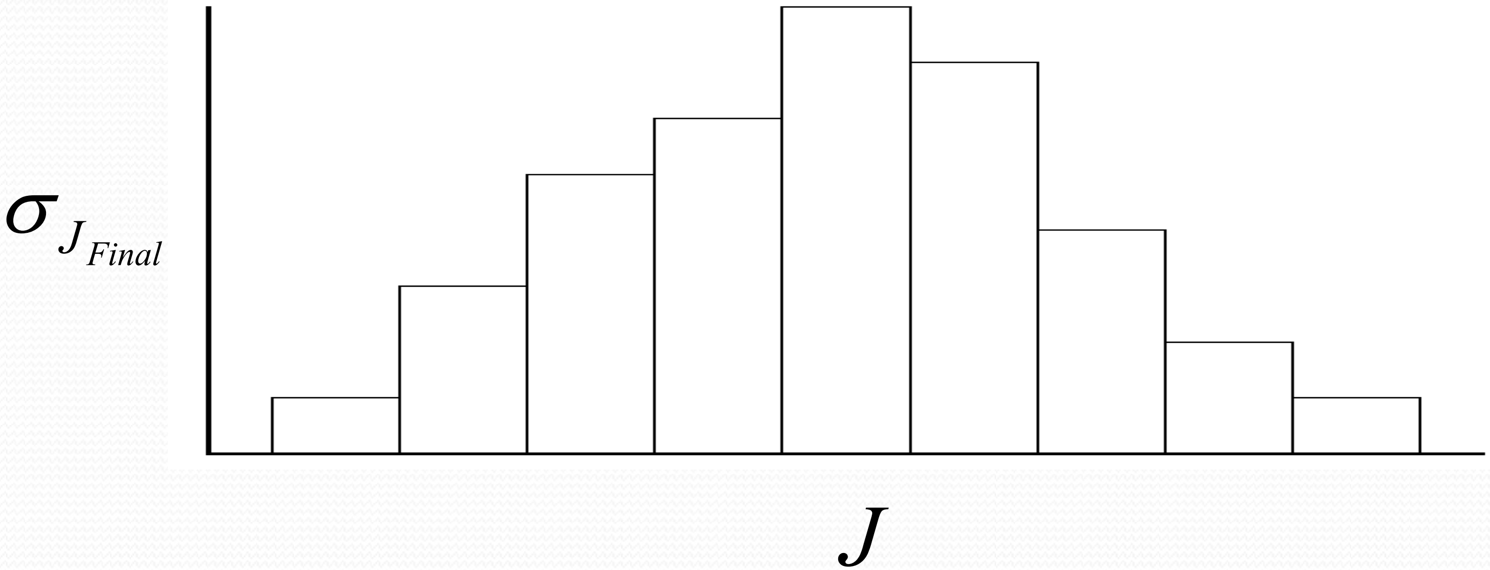
Decay: If $J_{final} < \ell_{\max}$ and $J_{final} < J_{comp}$

then σ to that level is proportional to $2J_{final} + 1$



Maximum σ for $J_{Final} \approx \ell_{\max}$

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Spherical symmetry:

Level

J

States

$m_Z = -J$ $\qquad$ $m_Z = J$

$$\sum = 2J + 1 \text{ states}$$

Deformed nuclei:

$5/2$

$\pm 5/2 = K \qquad 5/2 = J$

$\pm 3/2 = K \qquad 5/2 = J$

$\pm 1/2 = K \qquad 5/2 = J$

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Also build bands

J, K=0	J, K=J
4	J+2
2	J+1
0	J

New approach to Hauser Feshbach

$$T_{in} \rightarrow \langle j m_j J_+ K_+ | J_c K_c \rangle^2 T_{in}$$

$$T_{out} \rightarrow \left\langle j_{out} m_{j_{out}} J_f K_f \middle| J_c K_c \right\rangle^2 T_{out}$$

$$J_+ = J_{in}$$

$$K_+ = K_{in}$$

Population distribution is similar
Compound J distribution is similar
K degeneracy is broken

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Decay ratios differ

0, 2, 4, 6 sequence in spherical nucleus

has $1:5:9:13$ for population ratio

Deformed nucleus has $K = 0$ band so each level

is non-degenerate

Ratio: $1:1:1:1$

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Cross Section Ratio Values for n + ^{182}W

Reaction	Bombarding Energy (MeV) 0.5	1	4	10	14
(n,α) (n,p)	1.67	1.77	1.85 0.98	1.51 1.0	1.3 1.0
(n,2n) (n,nα+αn)					0.97 1.82
(n,γ) (n,n) J=0 K=0+	1.12 0.56	1.07 0.52	1.03 0.36	0.27	0.24
(n,n′) J=2 K=0+ (n,n′) J=4 K=0+	2.12 3.25	2.21 3.44	1.25 2.84	1.26 2.15	1.14 1.96
(n,n′) J=6 K=0+ (n,n′) J=0 K=0+		3.56	3.75 0.377	2.93 0.273	2.71 0.24
(n,n′) J=8 K=0+ (n,n′) J=2 K=2+			3.6 0.75	3.59 0.59	3.58 0.54

Cross Section Ratio Values for n + ^{183}W

Reaction	Bombarding Energy (MeV) 0.6	1	4	7	14
(n,α)	1.9	2.05	2.2	2.0	1.46
(n,p)				1.0	1.0
(n,2n)				1.07	1.01
(n,nα+αn)				1.52	1.44
(n,γ)	1.1	1.04	1.015	1.01	
(n,n) $J=1/2$ $K=1/2^-$	0.18	0.19	0.18	0.16	0.13
(n,n′) $J=3/2$ $K=1/2^-$	0.68	0.71	0.59	0.47	0.37
(n,n′) $J=5/2$ $K=1/2^-$	1.14	1.18	1.0	0.81	0.64
(n,n′) $J=7/2$ $K=1/2^-$	1.6	1.61	1.18	1.12	0.88
(n,n′) $J=3/2$ $K=3/2^-$	0.5	0.61	0.54	0.46	0.38
(n,n′) $J=5/2$ $K=3/2^-$			3.6	3.59	3.58
(n,n′) $J=9/2$ $K=1/2^-$			0.75	0.59	0.54
(n,n′) $J=11/2$ $K=11/2^+$	0.56	0.65	1.05	0.94	0.83

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All levels with $K = 0$ have degeneracy one

All levels with $K \neq 0$ have degeneracy two

For levels $\geq\sim$ 1.5 MeV above threshold reduces range of sigma values – enhances those with small J

K mixing important as energy increases

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Matrix elements ~ 10 keV couple (J,K) states to $(J,K\text{-}1)$ and $(J,K+1)$

New code allows for mixing

Expect mixing ≈ 0 for U < 4 MeV and U > 30 MeV

Level Density low for U < 4 MeV

Decay width large for U > 30 MeV

Introduction of mixing <u>does not</u> restore spherical limit

Isospin Mixing:

Also involves addition of Clebsch-Gordan coefficients

Proton incident on target with N > Z

Target isospin $T_0 = T_Z = \frac{N-Z}{2}$

Proton has $T = 1/2, T_Z = -1/2$

Coupling: $\frac{1}{2T_0 + 1}$ to $T = T_o + 1/2$, $T_Z = T_0 - 1/2$

$\frac{2T_0}{2T_0 + 1}$ to $T = T_0 - 1/2$, $T_Z = T_0 - 1/2$

Decay of $T = T_0 + 1/2$ is mostly protons

Decay of $T = T_0 - 1/2$ is mostly neutrons

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Ratio of level densities is large

Energy shift

$$\Delta E = a_a\left[-\frac{(N-Z)^2}{A}+\frac{(N-Z+2)^2}{A}\right] \cong 24\left[\frac{4(N-Z)+4}{A}\right]$$

for $A \approx 40 \qquad \Delta E \approx 6\,\mathrm{MeV}$

$A \approx 100 \qquad \Delta E \approx 9\,\mathrm{MeV}$

$A \approx 200 \qquad \Delta E \approx 19\,\mathrm{MeV}$

Level density ratio

$A \approx 40 \qquad R = 60$

$A \approx 100 \qquad R = 2.2\times 10^4$

$A \approx 200 \qquad R > 10^{10}$

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All mixing is down

$$R = \frac{\left(\dfrac{\sigma(p,p')}{\sigma(p,\alpha)}\right)}{\left(\dfrac{\sigma(\alpha,p)}{\sigma(\alpha,\alpha')}\right)} > 1$$

for proton and alpha induced reactions through the same compound nucleus

Angular Momentum Effects

- Without isospin $R \approx 1.15$
- With isospin conserved $(A \approx 60)$ $R \approx 1.7$
- Experiment $R \approx 1.45$
- Result: Mixing ~ 50% before decay
- Measurements for E ~ 18-22 MeV
- Show mixing is 40-60% for A ~ 60-70
- If mixing is 100%, recover result of Hauser-

  Feshbach code without isospin

K mixing differs

- Only two values of T – many values of K
- Big difference in branching ratios for two T values
- Smaller difference for K
- Mixing in both directions for K – only one direction for T
- Complete K mixing does not restore spherical limit

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Bohr and Mottelson (vol. II, pg. 39) state that
$\rho(U,J)$ for deformed nucleus is

$$\sigma_\perp^2 \rho_s(U,J)$$

($\sigma_\perp^2$ times spherical)

Direct calculation shows that both J and K dependence differ from Bohr-Mottelson result.

SUMMARY

- New approach proposed for Hauser Feshbach calculations in deformed nuclei
- Can accommodate both spherical and deformed nuclei in same calculation
- Code is slower (~8x) than conventional HF
- Cross sections for low J enhanced and for large J are reduced
- Cross sections for (n,2n), (n,p) and (n,γ) change less; similar changes in ^{183}W(n,n′), ^{168}Er(n,n′),^{22}Ne(α,n) and ^{25}Mg(n,n′).

SUMMARY (Continued)

- Look at effects on surrogate reactions
- Code improvements:
  - Add isospin to code
  - Add fission channel
  - Add Angular distributions

The End